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AN INTRODUCTION

TO THE STUDY OF

HEAT.



15.

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HEAT.

SECT. I.—GENERAL EFFECTS OF HEAT.

1. Common experience makes us acquainted with the fact, that some bodies, when we approach or touch them, affect us with the sensation of warmth. The cause of this sensation is called HEAT.

2. Till the latter part of the last century Heat was generally regarded as a material substance, of which the entrance into our bodies causes the sensation of warmth, while the departure of it causes the sensation of cold.

3. It has now been conclusively proved that Heat is not Matter, but that the application of heat to a body causes a vibration of the particles composing the body; that this vibration increases in intensity as the body receives more heat; and that what in our sensation is *Heat* is in the body nothing but *Motion*.

4. We will first consider what knowledge about heat we can acquire by some simple experiments:

Place a hand near a fire: we perceive the sensation of warmth; consequently the cause of this sensation, heat, must be in operation. Place it nearer: the sensation is stronger; and therefore the cause is more intense. The same holds if the fire is fiercer. We state these results in another way, by saying, that the heat enters the hand more rapidly, or, that a greater amount of heat enters in any specified time. Also, if we hold the hand near the fire *for a longer time*, it will grow warmer, that is, more heat enters, the longer we hold it in the same position.

5. Next, to ensure uniformity of burning and emission of heat, take a spirit lamp, and let it burn with considerable strength, so that its effects may be more marked: and

(a) Hold a piece of iron near the lamp, in the flame, and touch it at intervals. We find the sensation of heat stronger each time we touch the iron, that is, the *the power of the iron to give out heat increases*, the longer it remains in the flame.

(b) Take a glass tube with a bulb at the end, partly filled with mercury, such as we have in the ordinary thermometer, and hold the bulb in the flame. The mercury rises up the tube, that is, *the volume of mercury has been increased* by the application of heat.

This result is also found in *(a)*, but the *increase in the volume* of the iron is so small, that it cannot be perceived without minute and careful measurement.

(c) Suspend a lump of ice, in a vessel of glass, in the flame. The ice melts, that is, there has been a *change of state* from the solid to the liquid state. After this, if the water is kept in the same position, and the hand is dipped into it at intervals, we find, as in *(a)*, that its power of giving out heat increases.

(d) If the water remains over the flame long enough, and the flame is strong enough, the water will begin to boil away, that is, it will be turned into steam. Here we have another *change of state*, from the liquid to the gaseous state.

In *(c)* and *(d)* there is a change in volume; in *(d)* an increase; in *(c)* a decrease, when the ice melts, and for some little time afterwards, and then there is an increase till the water begins to boil.

6. These experiments shew the various effects produced by the entrance of heat into bodies, and we see that we may have

(i.) A change in the power of the body to give out heat.

(ii.) A change of volume.

(iii.) A change of state.

7. TEMPERATURE. *The temperature of a body is its state with regard to sensible heat, and is estimated by the power that the body has of giving out heat.*

When this power increases, the temperature is said to rise; when it decreases, the temperature is said to *fall*.

8. We now proceed to explain how changes in temperature may be accurately determined: and, first, we will explain how a change of temperature in one body indicates a change of temperature in an adjacent body.

9. Heat can be transferred from one body to another. A smoothing-iron, such as is used by hatters and tailors, when placed on a heated stove, rapidly receives heat from the stove, and soon becomes too hot for us to touch. If we then remove it from the stove and place it on a cold iron stand, we shall find that heat is gradually communicated from the hot to the cold body, and that the temperature of the former is continually decreasing, while that of the latter is continually increasing.

10. "Hot bodies cannot be placed in contact with, or in the neighbourhood of, colder ones, without communicating to these part of their heat. When a lump of hot iron is taken out of the fire, how can we prevent it from communicating its heat to the surrounding matter? Lay it on the ground, or on a stone, it very quickly communicates to them a part of its heat: lay it on wood, or any other vegetable matter, it heats them in a very short time to such a degree as to set them on fire: let it be suspended in the air by a wire, it communicates heat to the air in contact with it."—*Black.*

11. Now imagine a cylindrical glass vessel A to be filled with *cold* water and placed in a larger cylindrical vessel B; and suppose the space between the exterior

surface of A and the interior surface of B to be filled with *hot* water. The water in A at once begins to gain heat, and the water in B loses heat: and this process goes on, till the water in both vessels is in such a state, that no more heat passes from B to A than that, which passes from A to B. The water in both vessels is then said to be *at the same temperature.*

12. Black, in 1767, made important discoveries in reference to what he called the *equilibrium of heat*, and enunciated the following principle: "We must adopt, as one of the most general laws of heat, that all bodies communicating freely with each other, and exposed to no inequality of external action, acquire the same temperature."

This Law of Heat is now known as *Prevost's Theory of Exchanges*, which may be stated thus:

All bodies communicating freely with each other, and exposed to no inequality of external action, are constantly giving out and receiving heat; and the higher the temperature, the more heat is given out; so that a body of a temperature higher than that of a second body gives out more heat to that second body than it receives from it, and thus the first falls and the second rises in temperature, till their temperatures are equal, and then each keeps giving to the other as much heat as it receives from it.

13. Another consequence of imparting heat to bodies is the expansion of their volume. In the case of *solids*

this effect is almost universal. If a polished cylinder of tin, which just passes through a ring, be heated to the temperature of boiling water, it will no longer pass through the ring, and will be found enlarged in all its dimensions. When the cylinder has been cooled it resumes its original volume, and will again pass through the ring.

An exception to this law is observed in the behaviour of india-rubber, which contracts under the influence of heat.

14. The wheelwright and the cooper avail themselves of the tendency of iron to contract while it cools. A tire or hoop of red-hot iron is securely fastened to the rim of a wheel or the surface of a cask, and then is suddenly cooled by the application of cold water: the iron contracts, and binds the work with great force. The rivets of armour-plates are made red-hot before they are driven in.

15. "The expansion caused by heat causes some bodies to crack and break in pieces when they are suddenly heated or cooled. When, for example, heat is suddenly applied to a part of a glass vessel that is not very thin, the heat expands that surface of the glass to which it is applied, and continues to expand it more, before it can penetrate to the other surface; as this last is not yet expanded, the glass is necessarily strained or stretched as if a force were applied to alter its form, and this force it cannot long withstand on account of its

brittleness. It is therefore split or broken. And the same must happen to bodies of this kind when, after being heated, they are suddenly cooled. In both cases the fissure always begins in the coldest side. Thus if hot water be poured suddenly into a cold glass, the glass may be cracked from the outside, and if the bottom of a cold glass be set in a basin of hot water, the glass may be cracked from the inside."—*Black.*

16. In the case of *fluids* the expansion attending the application of heat is more apparent. If oil or spirit of wine be put in a round glass with a long and slender neck, so as to fill only the round body of glass, and if the glass be then set in hot water, the application of heat will cause the fluid to swell and rise in the neck.

17. A remarkable exception to the law of expansion of bodies under the influence of heat occurs in water. This fluid expands during its passage from the liquid to the solid state. As water cools, it contracts, till it reaches a certain temperature; but shortly before it freezes it begins to expand, and continues to expand till just before it becomes ice.

The expansion of water during its conversion into ice is shewn by the fact that ice swims on water.

The expansive force of water when freezing causes water-pipes to burst, and stones in the pavement to be raised or loosened.

18. When heat is applied to *gases*, the effect is to expand them with great rapidity. When a liquid passes

into the gaseous state the process is called *Vaporization*. "The liquid is by this process converted into an elastic vapour, that is, a fluid extremely rare, light and expansive, like air; capable, like it, of being easily reduced into less space, by external pressure; and resisting, like it, the force which thus compresses it."—*Black*.

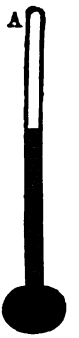
19. STEAM is the transparent and invisible vapour that rises from water *at the boiling point*.

20. "Put a teaspoonful of water into a globe of glass capable of holding several gallons, and suppose this vessel exhausted of air. If we apply heat to the globe we shall presently perceive the water to gradually disappear, so that the globe will seem empty. But the fact is that it is completely filled with the water, now existing in the form of a perfectly transparent vapour; for, if the heat be still further increased, the expansive force of what now fills the globe will also increase to such a degree, as even to burst it."—*Black*.

SECT. II.—THERMOMETRY.

THE MERCURIAL THERMOMETER.

21. The Mercurial Thermometer is an instrument constructed to measure temperatures by means of the extent of the expansion or contraction of mercury.



It consists of a glass tube of uniform bore closed at *A*, and terminating at the other end in a bulb. The bulb contains mercury; which extends part of the way up the tube. The space between the mercury and the top of the tube is a vacuum.

If the mercury in the instrument be subjected to an increase of heat, it expands and rises higher in the tube.

22. In the construction of the instrument observe

(*a*) That, for an accurate instrument, the tube must be of *uniform bore*, so that equal lengths of the tube may contain equal volumes of mercury.

(*b*) The way in which the mercury is made to enter a narrow tube. The tube having been cut of the proper length, one end is melted by heat and then blown into a bulb: the other end is left open. The bulb is then warmed, in order to expel the air from it, and the open end of the tube is plunged into a vessel of mercury. During the cooling of the bulb, the mercury rises into the tube.

(*c*) The vacuum at the top of the tube is obtained by making the mercury in the tube boil, before the upper end is closed; the mercury expels the air through the opening, and when the tube is completely filled with mercury or vapour of mercury, the opening is closed by

a blow-pipe flame. The mercury sinking, as it cools, leaves a vacuum in the upper part of the tube.

23. To graduate a thermometer, the portion of the instrument containing the mercury is placed in pounded ice in a *melting* state: the mercury shrinks; the column descends, and finally becomes stationary. The point, at which it rests, is marked; this is *the freezing point* of the thermometer.

The instrument is next placed in the vapour of water boiling under a given atmospheric pressure: the mercury expands; the column rises, and finally becomes stationary. The point, at which it rests, is marked; this is *the boiling point* of the thermometer.

The space between the freezing point and the boiling point is divided into equal spaces, called degrees.

In the Centigrade Thermometer freezing point is 0°, and boiling point 100°.

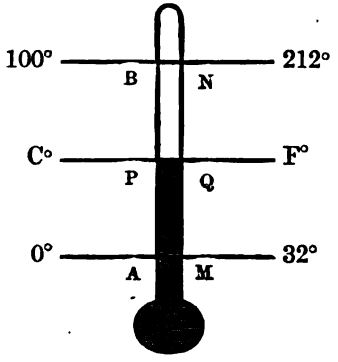
In Fahrenheit's Thermometer freezing point is marked 32° and boiling point 212°.

In Reaumur's Thermometer freezing point is marked 0° and boiling point 80°.

24. Having given the number of degrees on Fahrenheit's Thermometer, to find the corresponding number of degrees on the Centigrade Thermometer.

Let AM be the line at which the mercury stands at freezing point,

BN.....at boiling point.



Then

AM and BN are marked 0° and 100° on the Centigrade scale 32° and 212°.....Fahrenheit

Let the mercury stand at the line PQ, and suppose the graduations on the scales to the $C°$ and $F°$ respectively.

$$\text{Now } \frac{AP}{AB} = \frac{MQ}{MN},$$

$$\text{or } \frac{C}{100} = \frac{F-32}{212-32},$$

$$\text{or } \frac{C}{100} = \frac{F-32}{180};$$

$$\therefore \frac{C}{5} = \frac{F-32}{9},$$

and from this equation we can find C when F is given and F when C is given.

25. To compare the scales of the Centigrade and Reaumur's Thermometer, we proceed in the same way,

putting 0°, $R°$, 80° instead of 32°, $F°$, 212° respectively, and we obtain

$$\frac{C}{100} = \frac{R}{80},$$

$$\text{or } \frac{C}{5} = \frac{R}{4}$$

Hence the three scales are thus connected,

$$\frac{C}{5} = \frac{F-32}{9} = \frac{R}{4}$$

26. The following examples will shew how to find the number of degrees marked on any one of the three scales, when the number marked on one of the other scales is given.

Ex. (1) What reading on the Centigrade scale corresponds to 56° Fahrenheit?

$$\text{Since } \frac{C}{5} = \frac{F-32}{9},$$

$$\text{and } F = 56,$$

$$\frac{C}{5} = \frac{56-32}{9};$$

$$\therefore 9C = 5 \times 24,$$

$$\therefore C = \frac{120}{9} = 13\tfrac{1}{3},$$

$\therefore$ the reading on the Centigrade scale is $13\frac{1}{3}$ degrees.

Ex. (2) What reading on the Fahrenheit scale corresponds to 14° Centigrade?

$$\text{Since } C = 14,$$

$$\frac{14}{5} = \frac{F-32}{9};$$

$$\therefore 126 = 5F-160,$$

$$\therefore 5F = 286,$$

$$\therefore F = 57\tfrac{1}{5}.$$

that is, the reading on the Fahrenheit scale is $57\frac{1}{5}°$.

Ex. (3) If the sum of the readings on a Centigrade and a Reaumur be 90, what is the reading on each?

Here we have two equations, from which we can find C and R,

$$\frac{C}{5} = \frac{R}{4} \ldots (1)$$

$$C + R = 90 \ldots (2)$$

$$\left.\begin{aligned} \therefore 4C &= 5R \\ 4C + 4R &= 360 \end{aligned}\right\};$$

$$\therefore 4R = 360 - 5R,$$

$$\therefore 9R = 360,$$

and so $R = 40$ and $C = 50$.

EXAMPLES.

1. Give the number of degrees in the Centigrade and Reaumur's scale respectively that correspond to the following readings on Fahrenheit's scale,

(1) 30°, (2) 45°, (3) 56°, (4) 0°, (5) − 7°, (6) − 45°.

2. Give the number of degrees in the Centigrade and Fahrenheit's scale respectively that correspond to the following readings on Reaumur's scale,

(1) 5°, (2) 20°, (3) 0°, (4) − 18°, (5) − 64°, (6) 120°.

3. Give the number of degrees in Fahrenheit's and Reaumur's scales respectively that correspond to the following readings on the Centigrade scale,

(1) 16°, (2) 45°, (3) 110°, (4) 0°, (5) − 15°, (6) − 24°.

4. At what temperature are the readings on Reaumur, Centigrade and Fahrenheit proportional to 4, 5, 25?

5. If the sum of the readings on a Centigrade and Fahrenheit be 60, what is the reading on each?

6. At what temperature will the degrees on Fahrenheit be five times as great as the corresponding degrees on the Centigrade?

(7.) At what point do Fahrenheit and the Centigrade mark the same number of degrees?

(8.) Show how to graduate a Thermometer on whose scale 20° shall denote the freezing point, and whose 80th degree shall indicate the same temperature as 80° Fahrenheit.

(9.) The sum of the number of degrees indicating the same temperature on the Centigrade and Fahrenheit is 88: find the number of degrees on each.

(10.) At what temperature will the degrees on Fahrenheit be 3 times as great as the corresponding degrees Centigrade?

(11.) The number of degrees indicated at the same instant by a Centigrade and a Fahrenheit's Thermometer are as 5: 17; determine the temperature.

(12.) What is the temperature when the number of degrees on the Centigrade is as much below zero, as that on Fahrenheit's is above zero?

(13.) One Thermometer marks two temperatures by 9° and 10°; another Thermometer by 12° and 14°; what will the latter mark, when the former marks 15°?

(14.) One Thermometer marks two temperatures by 8° and 10°; another Thermometer by 11° and 14°; what will the latter mark, when the former marks 16°?

(15.) If the difference of the readings on Fahrenheit and Reaumur be 47, what are the readings? If the difference increase by a given number of degrees, find how much each of the Thermometers has risen.

(16.) In De Lisle's Thermometer (which is much used for scientific investigation in Russia) the freezing point is 150° and the boiling point zero. What degree of this Thermometer corresponds to 47° Fahrenheit?

(17.) At what temperature is the sum of the readings on Reaumur, Centigrade, and Fahrenheit 212?

27. The advantages of employing mercury in the construction of a thermometer are:

(a) It is a liquid that may be readily obtained in a state of purity.

(b) It gives out and takes in heat very quickly, and therefore soon comes into equilibrium of temperature with a body in contact with it.

(*c*) Its capacity for heat is very small, so that if it be brought into contact with a heated body, from which it takes heat, the temperature of the body is but slightly decreased by the abstraction of the small quantity of heat, required to raise the temperature of the mercury up to that of the body.

28. A standard thermometer is kept at Kew, by which other thermometers can be tested and corrected. The following are rough tests of the value of a thermometer, when no standard instrument is at hand, wherewith to test it:—

(*a*) When the bulb and stem, up to the top of the mercurial column, are immersed in melting ice, the top of the mercury should rest at 0° C.

(*b*) When the instrument is suspended in the vapour of water boiling under a certain atmospheric pressure, the mercury should rest at 100° C.

(*c*) When the instrument is turned upside down, some of the mercury should run down and completely fill the end of the tube; which it will not do if any air has been left in the instrument.

(*d*) A small column of mercury should be detached from the rest by a jerk, and made to pass, by inclining the tube, from one portion of the bore to another. If the scale be properly graduated, this column will fill an equal number of degrees in each part.

The fixed points in the Thermometric Scale, determined by the melting of ice and the boiling of water, were first suggested by Newton. Hooke had announced in 1664 that the temperature of melting snow is always the same. This is very nearly true, though the temperature is slightly lowered by an increase of pressure.

Hooke also announced, in 1684, that boiling water, under the same pressure, is always of the same temperature. This is not true, for water boils at a different temperature in vessels of different materials. But the steam rising from water, boiling under the same pressure, is as nearly as possible of the same temperature.

30. The glass tube of a thermometer, in consequence of its exposure to heat during the process of construct-

ing the instrument, is found to contract gradually for some months. Hence the mercury, when placed in melting ice, will stand somewhat higher than the freezing point on the scale. To avoid this error, the tube should not be graduated till some time after it has been filled.

31. Since mercury freezes at about —38° Fah. it cannot be employed to determine very low temperatures, and for this purpose alcohol is used as a thermometric substance, because it has never yet been frozen.

32. Two thermometers, with tubes of uniform bore, *filled with the same liquid*, whose freezing and boiling points have been accurately determined, will not necessarily agree at intermediate temperatures, because the glass of one tube may not expand (or contract) in the same degree as the glass of the other. To avoid this difference as much as is possible, the best thermometers in this country are made of the same kind of glass.

When the thermometers are *filled with different liquids*, they do not in general agree at intermediate temperatures, because the liquids do not expand uniformly.

MAXIMUM THERMOMETER.

33. This is an instrument constructed to mark the highest temperature that occurs within a given time.

A simple form of the instrument is that, in which the stem of a common thermometer is fixed horizontally, with a small piece of iron wire moving freely in the tube. When the temperature rises, the mercury pushes the wire before it; but when the temperature falls, the mercury contracting leaves the wire in the furthest position, to which it had been driven, and thus the maximum temperature between two observations is discovered.

45. A simpler form of a maximum thermometer has been constructed by Negretti and Zambra. It is a common thermometer, placed horizontally, with a contraction in the tube just above the bulb. The mercury will pass through this contracted part during its expansion, but not during its contraction. Thus it marks the highest temperature reached since the last observation.*

MINIMUM THERMOMETER.

35. This is an instrument constructed to mark the lowest temperature that occurs within a given time.

The fluid employed is alcohol; the instrument is placed horizontally; and immersed in the fluid in the

* A form of maximum thermometer much in use is that invented by Phillips, in which about half an inch of the mercury in the stem is separated from the remainder by a small portion of *air*. The instrument is placed horizontally, and the detached part of the mercury is *pushed on* when the mercury in the bulb expands, but it is *not drawn back* when the mercury in the bulb contracts.

tube is a small index of enamel. As the alcohol recedes, it carries with it the index, with one extremity just at the end of the fluid column; as the alcohol expands, it does not carry the index with it, and thus the lowest temperature between two observations is recorded.

THE AIR THERMOMETER.

36. A glass tube, open at one end, is blown into a bulb at the other. The bulb is warmed, and the tube is then set upright, with its open end in some coloured liquid. As the bulb cools, the air in it occupies less space, and the liquid rises in the tube. The liquid sinks when the temperature of the air in the bulb is increased.

By affixing a graduated scale to the tube, the extent of increase or decrease in the column of liquid can be estimated.

37. The advantages of such a thermometer are:—

(i.) That it is easily made.

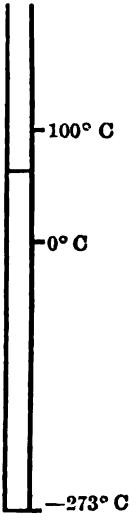
(ii.) That the column of liquid rises or sinks further, for a given change of temperature, than the column in a thermometer, in which mercury is employed.

(iii.) That the changes of temperature are indicated *rapidly*.

(iv.) "The scale of temperature, as indicated by an air thermometer, has this advantage over the scale indi-

cated by mercury, or by any other liquid or solid, that, whereas no two liquid or solid substances can be made to agree in their expansion throughout the scale, all the gases agree with one another."—*Maxwell.*

The disadvantage of such a thermometer is, that the height of the column of liquid is affected by the external pressure of the atmosphere, and that we cannot estimate the temperature, as indicated by the Air Thermometer, without taking into account the height of the Barometer at the same time and place.



38. A simpler form of the Air Thermometer is that of a long tube of uniform bore, closed at one end, and standing with the open end uppermost, the air (or gas) in the lower part of the tube being separated from the external air by a small column of mercury. If the lower part of the tube be warmed (or cooled,) the index rises (or sinks) very rapidly.

Sect. III.—EXPANSION OF GASES.

39. The following are the experimental laws connecting the pressure, volume, and temperature of a gas:

(i.) So long as the temperature remains the same,

the volume occupied by a gas varies inversely as the pressure.

This is known as Boyle's law, or as Mariotte's law.

(ii.) So long as the pressure remains the same, the volume of a gas, when raised from 0° C to 100° C, increases, for each degree centigrade, by the same fraction of its volume at 0° C, whatever be the nature of the gas.

This is called the law of Charles, or of Gay-Lussac, or of Dalton.

(iii.) So long as the volume of a gas remains the same, the pressure increases uniformly with the temperature.

40. Suppose the horizontal section of the tube of the Air Thermometer, described in Art. 38, to be one square inch. If at a temperature of 0° C, the air in the tube stand at the height of about 30 inches, at 100° C the air will stand at the height of about 41 inches. Hence, supposing the rate of increase uniform, for each degree centigrade of the rising temperature the volume of the air will have increased by $\frac{11}{3000}$ of its volume at the freezing point.

Now $\frac{11}{3000}$ is nearly equivalent to $\frac{1}{273}$, and if we take the latter fraction as the measure of the increase of volume of the air, the volume of air will be *doubled* at a temperature of 273° C.

Again, supposing the volume of air to *decrease* by the same fraction of its volume at 0° C for each degree centigrade as the temperature is lowered below the freezing point, it follows that the volume of air in the tube would be reduced to zero at a temperature of—273° C.

The reading of—273° C at the bottom of the tube is called *the absolute zero point* of the air thermometer. Temperatures reckoned from this point are called *absolute temperatures.*

41. A more exact approximation to the rate of increase (or decrease) in the volume of the air in the tube of the air thermometer is given by the following law: If the pressure remain constant, every increase of temperature of 1° centigrade produces in a given mass of air an expansion of ·003665 of its volume at 0° C.

This decimal ·003665 is called *the co-efficient of expansion* of air, and it is represented by a.

Hence, if V_0 be the volume of air at temperature 0° C,

and V_t be the volume of air at temperature t° C, under constant pressure,

$$V_t = V_0 + a\,t.\ V_0$$
$$= V_0(1 + a\,t)$$

The value of a is nearly the same for all gases, and it varies but little with the variation of the pressure.

SEC. IV.—EXPANSION OF SOLIDS.

42. Suppose a piece of lead in the form of a perfect cube, of which the edge is 1 inch, to be subjected to an increase of temperature. The result will be an increase in

(i.) The length of each edge of the cube.

(ii) The area of each side of the cube.

(iii.) The volume of the cube.

(1) It is found by experiment that an increase of temperature of 1° centigrade will increase the length of the edge of such a cube of lead by about ·000028 of an inch.

This decimal ·000028 is called *the co-efficient of linear expansion* of lead.

This co-efficient varies for different substances; for example, the co-efficient of linear expansion of gold is about half that of lead, or ·000014.

The co-efficients of linear expansion increase slightly with an increase of temperature, that is, the length of the edge of the cube is slightly more increased as the temperature is raised from 21° to 22° than the increase as the temperature is raised from 20° to 21°.

But, if we suppose that the expansion is regular as the temperature rises, and if

l_0 be the measure of the length of a solid body at 0° C,

l_t the measure of the length of the body at t° C,

k the co-efficient of linear expansion,

$$l_t = l_0 + l_0 t k$$
$$= l_0 (1 + t k).$$

Ex.—If a line of railway be laid with rails, which are 6 yards long, at 0° C., shew that to allow for the expansion due to an increase of temperature of 55°, the distance between two consecutive rails must not be less than about $\frac{7}{50}$ ths. of an inch.

The co-efficient of the linear expansion of iron is ·000012

Taking 1 inch as the unit of linear magnitude,

$$l_{55} = 216 (1 + 55 \times \cdot000012) \text{ inches.}$$
$$= 216 \times 1\cdot00066 \text{ inches,}$$
$$= 216\cdot14256 \text{ inches.}$$

Hence the space between two consecutive rails must be more than ·14 inches, that is, more than $\frac{7}{50}$ ths. of an inch.

(2) If k be the measure of the co-efficient of linear expansion, the area of each side of the cube, which at temperature 0° was 1 square inch, will at temperature 1° be $(1 + k)^2$ square inches, or, $(1 + 2k + k^2)$ square inches.

Now, as k is very small, k^2 may be neglected, and the new area may be taken as $(1 + 2k)$ square inches, that is the increase of area is $2k$ square inches.

Hence, the co-efficient of superficial expansion is 2 k, or *twice* the co-efficient of linear expansion.

(3) The increased volume of the cube will be $(1 + k)^3$ cubic inches, or $(1 + 3k + 3k^2 + k^3)$ cubic inches.

Neglecting the very small numbers $3k^2$ and k^3, the new volume may be taken as $(1 + 3k)$ cubic inches, that is, the increase of volume is $3k$ cubic inches.

Hence, the co-efficient of cubical expansion is $3k$, or *three* times the co-efficient of linear expansion.

SECT. V.—MEASURE OF HEAT.

43. To measure quantities of heat we must have a unit of heat, called a Thermal Unit, as a standard of measurement.

Such a unit is the quantity of heat required to produce a definite effect, as, for example,

(i.) To convert a pound of ice at 0° C into water at 0° C, or

(ii.) To raise a pound of water from one definite degree of temperature to another definite degree, as from 20° C to 21° C, or

(iii.) To convert a pound of water at 100° C into steam at 100° C.

The second of these is the thermal unit, to which we shall refer hereafter.

44. If a substance (A) requires more heat to be applied to it, in order to raise it through a definite range of temperature, than that quantity of heat, which will raise an equal weight of a substance (B) through the same range, (A) is said to have a greater *capacity for heat* than that, which (B) has.

For example, if we place before a fire, and at equal distances from it, a quantity of water, and the same quantity of mercury, each of them contained in equal and similar glass vessels, and each having a thermometer immersed in it, we find that the mercury is warmed by the fire much faster than the water. This shews that mercury has less capacity for heat than water has: it requires a smaller quantity of heat to raise its temperature by the same number of degrees.

45. If we call the quantity of heat, that will raise a pound of *water* from 20° C to 21° C, the *unit of heat*, the capacity of another substance for heat will be measured by the number of units of heat, that will raise a pound of that substance from 20° C to 21° C.

46. The *Specific Heat* of a substance is the ratio of the quantity of heat, required to raise any weight of that substance one degree of temperature, to the quantity of heat, required to raise an equal weight of water through the same degree of temperature.

For, example, to raise the temperature of a pound of charcoal from 20° C to 21° C requires one-fourth of the quantity of heat, required to raise a pound of water from 20° C to 21° C. Hence, if the specific heat of water be represented by 1, the specific heat of charcoal will be represented by ·25.

47. The specific heat of a solid increases with an increase of temperature; thus, it requires more heat to raise a lump of iron from 20° to 21°, than from 19° to 20°. The specific heat of platinum increases much more slowly than that of other metals; indeed, up to 300° C it does not increase at all.

As a solid approaches its melting point, the specific heat increases much more rapidly.

The specific heat of liquids usually increases with the temperature.

"A substance when liquid has usually a greater specific heat than the same substance in a solid state. Thus the specific heat of ice is only half the specific heat of water."—*B. Stewart.*

Water has a higher specific heat than any known solid or liquid.

The specific heat of a given mass of gas remains the same at all temperatures.

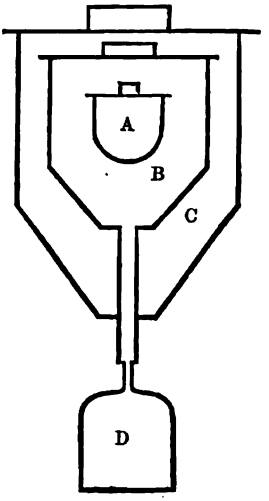
48. In calculations with regard to measures of heat it is assumed that, if a certain quantity of heat will

raise a pound of water through any one degree of temperature, *twice* the quantity will be required to raise *two* pounds of water through the same degree of temperature.

EXPERIMENTAL METHODS OF MEASURING QUANTITIES OF HEAT.

49. A minute account of the various methods of estimating the quanties of heat, that enter or leave bodies under particular circumstances, is beyond the scope of this treatise. We shall mention briefly three of the methods.

1. The Method by Melting Ice.



A is a vessel made of thin copper, containing the substance from which the heat is to escape.

B is a larger vessel, surrounding A, and filled with ice at the melting point.

C is a vessel surrounding B, and filled with ice at the melting point.

The ice in C prevents any heat from coming from the external air to B. Heat

passes from the body in A into the ice in B. Some of this ice is melted, and the body in A grows cool, and this process will go on, till the body is cooled to the melting point of ice.

The water from the melted ice in B runs through an aperture into a vessel D, and from the weight of this water we can estimate the amount of heat that has passed out of the body in A.

This method is inexact, because some of the water, that results from the melted ice, remains in the vessel B, adhering to the ice.

This instrument is called *The Calorimeter.*

II. THE METHOD OF MIXTURE.

In this method we estimate the amount of heat, that passes *out* of a body, by the increase of temperature in another body, *into* which the heat passes.

A body of known weight and temperature is immersed in water of the same weight and of known temperature. From the temperature of the water, after it and the body have reached a state of equilibrium of temperature, the quantity of heat, that has passed out of the body, can be estimated.

III. THE METHOD OF COOLING.

In this method we estimate the amount of heat. that passes out of a body at a temperature T, by the *time.* in which the body cools down to a temperature *t,* as com-

pared with the time in which an equal volume of water, under the same external circumstances, cools down from temperature T to temperature *t*.

Sect. VI.—LATENT HEAT.

50. The application of heat to a body may cause a change of state, without causing at the same time a change of temperature.

Thus, when pounded ice is just beginning to melt, its temperature is 32° F., and during the whole time of its conversion into water, if the ice and water be stirred, so as to mix them, a thermometer placed in the mixture will mark 32° F.

Again, whatever time is employed to heat water from its ordinary temperature of 50° F. to 212° F., the same fire must be applied five times as long to convert it all into steam. Yet all this time a thermometer held in the steam shews only 212°. On the other hand a pound of water converted into steam, and passed in that form into forty pounds of water will raise its temperature from 50° to 70°.

51. The quantity of heat, which enters (or leaves) a body without increasing (or diminishing) the temperature of the body, is called *Latent Heat*. It is called *latent*, because the thermometer gives no indication of its entrance or departure.

52. If water at 190° F. be mixed with an equal volume of *water* at 32° F., the temperature of the mixture is $\frac{190° + 32°}{2}$, or, 111°.

But, on mixing water at 190° F. with an equal volume of *ice* at 32° F., Black found that, though the ice melted in a few seconds, the temperature of the mixture was only 53° F. This proved that a quantity of heat had been communicated to the ice, with the sole effect of changing its state, without changing its temperature.

53. When we say that the Latent Heat of ice is 79 thermal units, we mean, that to change a pound of ice at 0° C. into water at 0° C. requires as much heat, as will raise 79 lbs. of water from 20° C. to 21° C.

When we say that the Latent Heat of water at the boiling point is 536 Thermal units, we mean, that to convert a pound of water at 100° C. into steam at 100° C. requires as much heat, as will raise 536 lbs. of water from 20° C. to 21°C.

The quantity of heat, which is released by the condensation of vapour, or freezing of water, is exactly equal to that, which would be absorbed by the contrary process.

"We must carefully remember that all we know about heat is what occurs when it passes from one body to another, and that we must not assume that, after heat has entered a substance, it exists in the form of heat within that substance."—*Maxwell.*

SECT. VII.—DIFFUSION OF HEAT.

54. Heat can be transferred from one body to another in several ways, three of which—Conduction, Radiation, Convection—we now proceed to describe.

I. CONDUCTION.

55. The process, by which heat passes from hotter to colder parts of a body, or from one body to another in contact with it, is called the conduction of heat.

Heat flows more quickly through some substances than through others. The substances, through which it flows with greater facility, are called *better conductors*.

56. All metals are far better conductors than wood or stone or ivory.

The following are arranged in order of conducting power:—silver, gold, copper, zinc, iron, tin, steel, lead.

The wooden kettle-holder protects the hand from the heat of the metal; and pieces of ivory are inserted between the handle and body of a silver teapot, because ivory is a slow conductor of heat.

"A rod of iron, or copper, if one end of it be put in the fire, and made red hot, transmits the heat so quickly, and in such quantity to the other end, that it cannot be touched without burning the hand; while a stick of wood of the same size can easily be held by the one end, while the other is blazing."—*Black*.

57. The great conductivity of metals is turned to use in the *Safety Lamp*. A piece of wire-gauze, placed over a jet of lighted gas, does not allow the flame to pass through it. If the gas be allowed to pass through the wire-gauze, and then be lighted above, the flame burns on without reaching the jet. The cause of this is, that the heat of the flame is rapidly conducted away along the metal, so that there is not heat enough left at the point of contact to ignite the gas on the other side.

Sir Humphry Davy invented the safety-lamp, which is a lamp surrounded with wire-gauze. The explosive gases pass through this gauze, and burn inside the lamp, so as to warn the miner of their approach; but the flame has no power to ignite them outside the lamp.

58. Wool is a slow conductor: a blanket put round a lump of ice in an ice-box preserves it from melting for a long time.

Sand is a slow conductor: masses of red-hot iron may be safely carried in wooden barrows filled with sand.

The usual construction of fire-proof safes is, to put an iron box into one considerably larger, and to fill up the space between them with some slowly-conducting substance, such as felt.

59. The small conductivity of felt is turned to use in the *Norwegian Stove*. A wooden box is lined thickly

with felt, room being left in the centre for a stew-pan. The contents of the stew-pan are raised to the boiling temperature, and then the pan is put in the box, and covered over with a felt top. The cooking then goes on without any fire; for the temperature of the pan does not sink more than 1° C. in every fifteen minutes.

60. Bricks and straw are slow conductors: hence an ice-house is generally made of bricks, and straw is placed as a covering on the ice.

Stone is a better conductor than either brick or wood: hence houses in cold countries are usually built with bricks or wood; while stone is a more suitable material for hot climates.

61. Animal and vegetable substances are, in general, very slow conductors; thus the hair and the wool of animals, and the feathers of birds, protect them from the cold, and, by enclosing and retaining air, which is a still slower conductor, they increase the protection.

62. Fluids—(mercury is an exception)—conduct heat slowly, and gaseous fluids very slowly. "The heat of metals at the temperature of 120° F. is scarcely supportable, water scalds at 150°; but air may be heated to 240° without being painful to our organs of sensation.

Again, in the high northern latitudes a cold has been experienced, without injury, in which mercury froze; and if, in this state of the atmosphere, metallic sub-

stances, of the same temperature, were touched, a sensation like that of burning was experienced, and the part blistered."—*Sir H. Davy.*

63. Instances of the slow conduction of air are—Double windows, through which the warmth of a room escapes very slowly, because it has to pass through the air confined between the windows; and loose gloves, which are warmer in winter than tight-fitting gloves.

II. RADIATION.

64. The process, by which heat is transmitted *across an intervening space* from one body to another, is called *Radiation.*

65. Radiation and Radiant Heat conform to the same laws as Light; thus:—

(*a*) Radiant heat can pass through a medium without warming it in any appreciable degree.

(*b*) Rays of heat, like rays of light, travel in straight lines through a uniform medium.

(*c*) The heat-rays traverse the space between the bodies with very great rapidity.

"Radiant heat is the same thing as what is called light, only perceived by us through a different channel. The same radiation, which, when we become aware of it by the eye, we call light, when we detect it by a thermometer, or by the sensation of heat, we call radiant heat."—*Maxwell.*

66. Our chief supply of heat, received by the Earth from the Sun, reaches us by the process of Radiation.

When we stand before a fire the warmth we feel is caused chiefly by Radiation, because air is a bad conductor.

67. No known body allows heat-rays to pass through it without absorbing a portion of the heat. Substances, which do not absorb much of the heat, are called Diathermanous, and such as absorb much of it, or do not allow it to pass at all, are called Athermanous. Some colourless gases are diathermanous to a high degree. A substance may be transparent and yet not diathermanous. Hence the use of a glass screen before a bright fire. Plate-glass is more diathermanous than common glass, the former allowing 65, the latter 52, parts out of 100 of the heat to pass.

The solid possessing the highest diathermancy is Rock-salt, which allows 92 parts out of 100 to pass.

Lamp-black (which is the same substance as finely-divided charcoal) is a great absorbent of heat, and a sheet of paper coated with lamp-black is almost completely athermanous.

68. When radiant heat falls on a surface of polished metal, it is reflected just in the same way as rays of light. If at the point of incidence a normal be drawn to the reflecting surface, the lines of incidence and reflexion are in the same plane as the normal, and make equal angles with it.

Hence it is that, by exposing a concave surface of polished metal to the action of the rays of heat coming from a fire, the reflected rays may be concentrated in a focus, and their heat directed to an object between the reflecting surface and the fire.

This is the result obtained by the use of the Dutch Oven, the Plate-Warmer, and the Meat-Screen or Reflector.

"Polished silver reflects nearly the whole of the radiation that falls on it, absorbing only about a fortieth part and transmitting none."—*Maxwell.*

The disturbing effects of radiation on the Thermometer are greatly lessened by covering the bulb with polished silver.

69. Good reflectors are bad radiators and bad absorbers. "Vessels that are intended to retain their heat should be metallic and highly polished. Steam or air pipes for warming houses should be polished in those parts, where the heat is not required to be communicated, and covered with some radiating substance as lamp-black or plumbago in those rooms, which are to be heated by them. Culinary implements should be blackened, and not polished, on those parts, which are to receive heat. The heated surfaces of fire-places or stoves should not be metallic, but of earthy or stony materials, and in this case much more heat will be communicated by radiation."—*Sir H. Davy.*

Good absorbers are good radiators.

III. CONVECTION.

70. Convection of heat is the process, by which heat is transferred from one place to another, by means of the motion of a body, generally a fluid, carrying heat with it.

71. When a kettle filled with water is placed on the fire, heat is communicated to the water at the bottom by conduction; this water is rarified, and the pressure of the heavier water above, and on all sides of it, forces it up in a current, ascending in the middle of the kettle, while the colder water runs in currents, descending by the sides. This process goes on continuously, the colder water always sinking to the bottom of the kettle, receiving heat, and then expanding and ascending to convey heat through the whole body of water. These currents are called convection currents. If anything occurs to check the free circulation of a liquid, such as milk, which is being heated by this process, the layers nearest to the bottom receive too much heat, and the milk is "burnt:" and, to prevent this, we must assist the circulation by stirring the liquid occasionally.

72. The process of Convection of Heat is applied to the warming of buildings by hot water, or hot air. If a pipe be inserted near the top of a boiler in the basement of a house, and be carried up in any direction, and to any height, returning ultimately to the bottom of the boiler; if the boiler and pipe be then filled with water, and heat be applied to the bottom of the boiler, the current of heated water will constantly ascend through

the pipe at the top of the boiler, while water at a lower temperature will be constantly flowing into the boiler through the pipe at the bottom.

73. When a fire is lighted in a grate, there is above it a body of air in the chimney, at the same temperature as the outer air. The heat, derived by conduction from the fire, expands the air at the lower part of the chimney, and then by the process of convection of heat a current of warm air ascends the chimney. If the room were completely closed against the entrance of cold air by some other opening, the cold air would come down from the top of the chimney, beating down the smoke into the room. Hence the necessity for letting in fresh air to the room, by door or window or some other opening.

74. In a room, that has been much heated by respiration or the burning of lights, especially gas, the air near the ceiling becomes much higher in temperature than that in the lower parts of the room. Hence the necessity for making an outlet for this heated air near the ceiling, and for supplying its place by fresh air, admitted near the floor.

SECT. VIII.—FORMATION OF VAPOUR, DEW, &c.

75. When a liquid (or solid) is passing into the gaseous state, the process is called *Evaporation*. When

a vapour is returning to the liquid (or solid) state, the process is called *Condensation.*

76. Some solid bodies are constantly in a state of evaporation. Solid camphor is constantly emitting vapour, which is condensed and adheres, like ice-particles, to the top and sides of the vessel containing it. Ice is constantly evaporating: patches of snow gradually waste and disappear, even during a severe frost.

77. Vapour is constantly rising from the exposed surface of water, and the more copiously the warmer the water is. This vapour is much lighter than the atmosphere. The particles composing the atmosphere, being heavier than those composing the vapour, slip down past them, and the particles of vapour are forced upwards. When the vapour reaches the higher, and therefore colder regions, it is condensed into clouds and falls as rain, leaving only so much uncondensed as can remain vaporous under that temperature and pressure; for vapour can only exist at a certain pressure above a fixed temperature, and at a certain temperature below a fixed pressure.

Hence rain falls very freely in hot countries at certain seasons, when vaporization is going on rapidly and constantly.

So, again, in hot countries, that part of the atmosphere, which is close to the earth, receives heat from the earth, becomes lighter than the atmosphere above it, and is forced upwards.

THE FORMATION OF DEW, MIST, CLOUDS, RAIN, HAIL, AND SNOW.

78. The true explanation of the formation of dew was first given by Mr. Wells, a London physician, in 1814. It had been observed that a thermometer, placed on grass in the open air, when dew was being formed, indicated a temperature several degrees lower than that marked by a thermometer, suspended two feet above the grass. It was supposed that the formation of dew was *the cause* of the increase of cold. Mr. Wells, by a series of experiments, proved that dew is the effect of chilling by radiation.

79. Dew appears in an open grass field, during a still and bright night, from the following causes. The *upper* parts of the grass radiate their heat into the regions above, which send back no heat in return; the *lower* parts of the grass, from the smallness of their conducting power, transmit but little of the earth's heat to the upper parts, The grass being colder than the atmosphere, receives heat from the atmosphere, which consequently becomes colder, and, if its temperature be sufficiently decreased, it cannot hold all the vapour in it, which is therefore condensed into dew and deposited on the grass.

80. Dew appears chiefly, where it is most wanted, on herbage and low plants, avoiding in a great measure rocks, bare earth and water.

81. When dew is deposited on bodies, cooled below the freezing point, it is solidified into Hoar Frost and Rime.

82. A solid body, between a substance on the ground and the sky, prevents the substance from becoming cold by radiation, sending back to the substance the heat received from it. A very slight covering protects a plant from frost.

83. Dew is formed more freely on a *clear* night, because clouds radiate back the heat, intercepted by them in its progress from the earth upwards.

84. Dew is formed more freely on a *calm* night, because any agitation of the atmosphere tends to send continually currents of warmer air, which will replace the heat that substances lose by radiation.

85. Grass, on a clear and calm night, is much colder than the gravel or earth by its side, because heat is conducted better to the latter from the earth below.

86. Air, on a calm and clear night is colder at the surface of an open plain than at any point above the surface, for at least 200 feet; and frosts are less severe on hills of moderate height than on the neighbouring plains, when the night is still and the sky unclouded.

87. The leaves of trees often remain dry, while grass near the trees is covered with dew. This may be because more air is stirring about the tree, and because but few

of the leaves are exposed to the sky above, and because the air about the tree is warmer than that close to the grass.

88. "Bright metals, exposed to a clear sky, in a calm night, will be less dewed on their upper surface than other solid bodies, since of all bodies they will, in such a situation, lose the smallest quantity of heat by radiation, at the same time that they are capable of receiving by conduction at least as much heat as any others from the atmosphere, and more than any others from the solid substances, which they happen to touch."—*Wells.*

89. "Painted bodies radiate very fast. If part of a wooden pole be painted, and part not, the painted part, exposed in a clear night, will become considerably colder than the unpainted part. and in the morning dew will be found standing thick on the one, while there is little or none on the unpainted part."—*Herapath.*

90. Ice is obtained in hot parts of India by means of radiation. "Square holes, 30 feet wide and 2 feet deep, are dug in a large plain; the bottoms of the holes are covered for 8 inches thick with dry stems of Indian corn. On this are placed small unglazed earthen pans, 1 inch thick and 1¼ inch deep, filled with boiled soft water. If the night is calm and clear, they never fail to obtain ice, though the temperature of the air all through the night should never descend below 40° Fahr."—*Sir. R. Baker.*

91. At a certain temperature, and under a certain pressure, there is a limit to the quantity of vapour, that can be formed in a given space. This space is then said to be *saturated*.

"A vapour, which is at the greatest density and pressure corresponding to its temperature, is called a *saturated vapour*. It is then just at the point of condensation, and the slightest increase of pressure, or decrease of temperature, will cause some of the vapour to be condensed."—*Maxwell*.

92. The *Dew-point* is the temperature, at which the vapour in the atmosphere begins to condense.

To determine the dew-point, a glass vessel is cooled, till dew begins to be deposited on it, and its temperature (T) is observed: again, the temperature (t) of the vessel is observed immediately after the dew has disappeared. Then $\frac{1}{2}$ (T + t) is the dew-point.

93. From a moist and warm soil vapour rises, spreads itself into the colder air, and is condensed into small aqueous particles, which float in the air, and become visible as *Mist* or *Fog*.

94. *Clouds* are formed from the condensed vapours rising from the earth, and differ from mist only in occupying higher regions of the atmosphere.

95. It is not known whether the small particles composing mist and clouds are *hollow*, and filled with air

warmer than that around them, so that they float like balloons, or whether they are *solid* drops of water kept floating by air-currents.

When this watery vapour becomes more condensed, the particles unite and fall as *Rain*.

96. *Snow* is vapour suddenly condensed into the solid state.

97. *Hail* is formed out of rain-drops, that freeze as they fall through colder regions.

98. Mountains stop the currents of warm and moist air rising from the earth, and in part condense them, in part force them upwards to regions, where they are condensed and remain as mist, or fall as rain or snow.

99. The South-wind is moist and warm, and mixing with the colder air of northern regions results in clouds and rain.

100. The wind, that causes most rain in England, is the south-west, and hence the eastern counties have the smallest rain-fall, because the rain-wind has to cross the island, before it reaches them.

101. When the temperature of a portion of the earth's surface becomes higher, the air in contact with that surface is heated, expands, and rises, while its place is filled by colder air from lateral directions.

This is the cause of the *Land and Sea Breezes*, that blow regularly in hot countries near the coast, from the sea to the land during the day, and from the land to the sea at night. For, during the day, the land is more heated than the sea, and the air that rises from the land is replaced by colder air coming from the sea; but during the night, the land cools faster than the sea, and the contrary effect is produced.

102. The mists on low-lying marsh-lands in the evening are caused by the rapid cooling of the air when the sun has set.

The morning mists over rivers and lakes are caused by the water cooling much more slowly than the air, that is in contact with it.

103. In hot dry weather there is much more vapour in the atmosphere than in cold wet weather.

EBULLITION.

104. By the word *Ebullition*, or boiling, we mean the formation in any liquid of bubbles of vapour, whose internal pressure is just equal to the external pressure upon them.

105. The process of ebullition may be seen by heating water from below in a glass vessel. At first, when the water has become heated throughout, bubbles of the

air, which the water contained within it, form and rise and burst without any sound. Next, when the water at the bottom of the vessel is heated to the boiling point, bubbles of vapour are formed there; these bubbles struggle up into the colder water above, and are condensed and collapse with a noise, which we call *simmering* or *singing* When the temperature of the whole mass of liquid becomes nearly uniform, the bubbles of steam, as they are formed, rise to the surface, burst under the pressure of the atmosphere, and cast forth invisible steam.

NOTE.—That, which we call steam, issuing from the spout of a kettle of boiling water, is partly *condensed steam*, which is therefore visible, and partly *uncondensed steam*, which is invisible.

106. The temperature of ebulition increases with the pressure. If the pressure at the surface of a liquid, just beginning to boil, be increased, ebullition is checked, because the vapour-bubbles cannot form at the surface under the increased pressure.

On the other hand, if the pressure at the surface of a liquid, which has just ceased to boil, be decreased, ebullition will commence again. For example: fill a glass decanter half full of water, make it boil over a spirit-lamp, then cork it up, and, when ebullition has ceased, dash some cold water on the top of the decanter. The application of the cold water condenses the steam, lessens the pressure on the surface of the water, and makes it boil again.

107. The Atmosphere is most dense at the surface of the earth, and its density diminishes with its height. Hence, as one ascends a mountain, the weight of the incumbent air is diminished, and water boils at a lower temperature. At the top of Mont Blanc (15,600 feet) water boils at 85° C.

Roughly speaking, an ascent of 1080 feet produces a diminution of 1° C in the boiling point.

Hence arise the difficulties in cooking tea, and other food on the top of a high mountain, because it is impossible at a great altitude, unless the water be enclosed in a vessel with a tight-fitting lid, to heat it up to the temperature of 100° C, the ordinary boiling point.

108. As soon as ebullition commences, the temperature of the vapour, rising from the free surface of the liquid, is invariable, and continues so, till all the liquid has been converted into vapour.

The temperature of the liquid increases slightly, while ebullition is going on, and it is greater at the bottom of the vessel than at the top; yet still it is not so much above the boiling point as to prevent it from keeping the vessel from burning. Thus vessels of tin, copper, or any other metal may be exposed to the action of a very hot fire without fear of injury to them, if they contain water or some liquid, which, by its contact, will keep them from burning.

PAPIN'S DIGESTER.

109. Papin's digester is a copper vessel, having a lid nicely fitted to it and kept fast by screws. If this vessel be half-filled with water, and the lid screwed down tight, and if it be then set over a brisk fire, a portion of the water is soon converted into steam. The steam, being unable to escape, presses on the surface of the water, and prevents the conversion of any more of the water into steam, till the temperature of the water is raised *above the boiling point*. By the confinement of the steam thus produced, and the regular increase of the pressure on the surface of the water, the contents of the digester may be raised to a very high temperature. By this means substances, such as horn, cartilage, and bone, can be easily reduced to a jelly. A heat has been produced in the digester sufficient even for melting bits of tin and lead, suspended by wires in the midst of the vessel.

CONGELATION.

110. The process, by which water is converted into ice, is called *Congelation*.

The following is an explanation of the process, by which ice is formed on a sheet of water in a calm frosty night. The water at the surface is first chilled; it contracts, and, being more dense than the water below, it descends, and the lighter water from the bottom ascends. Thus, by means of convection currents, the whole of the

water is gradually cooled, till its temperature is 39° F. Then the water begins to expand, and the colder water is at the surface, till solid ice has been formed, which swims on the warmer water below it. The ice is then formed in layers, the number of which increases, in proportion to the intensity of the cold at the surface.

111. The expansion of water before its conversion into ice is of great importance. "It is owing to this that the great bulk of the water of rivers and lakes is protected from a freezing temperature, which would be fatal to the animals contained in them."—*Brande.* This expansion probably arises from the new arrangement taken by the particles of water on their approach to the state of solidifiation.

112. The force with which water expands during its conversion into ice, is very great. "Boyle found that water confined by a moveable plug, in a strong brass tube, three inches in diameter, lifted, while it froze, a a weight of 74lbs., with which the plug was loaded. The academicians of Florence burst a small hollow brass globe, the cavity of which was one inch in diameter, by filling it with water, which was afterwards frozen, and it was computed that the force necessary to the bursting of this ball was equal to a pressure of 27,720 lbs."—*Black.*

"The following experiment, performed by Major Williams at Quebec, is still more striking. He filled a 12-inch shell with water, and closed it with a wooden

stopper, driven in with a mallet. The shell was then exposed to the air, the temperature being -28° C. The water frose, and the bung was projected more than 100 yards, while a cylinder of ice, eight inches long, was protruded from the hole."—*Deschanel.*

REGELATION.

112. If the smooth surfaces of two pieces of ice be pressed together, the temperature is raised, and water is formed. When the pressure is relaxed, this water escapes, the temperature is suddenly lowered, and the pieces of ice are frozen together. This process is called *Regelation.*

GENERATION OF HEAT.

114. That heat is not a substance is certain from the fact that it can be generated by various processes. Such are—

(*a*) *Percussion.* When a rifle-bullet is fired at an iron target, the bullet and the target are heated. The *motion* of the bullet is suddenly stopped, and is transformed into *heat*; in other words, the motion of the mass of metal is transformed into motion of its particles.

Again, nails, that are required for brick-work, are made harder by hammering, and it is found that after

a few strokes the nail is extremely hot. When cooled, the nail becomes exceedingly brittle, and it will not bear a second hammering.

(*b*) *Compression.* When bars of metal have been subjected to great pressure between iron rollers, the sheets of metal, as they issue from the rollers, are very hot.

(*c*) *Friction.* The rubbing together of two pieces of very dry wood produces fire; a marble, rubbed briskly on a hearth-stone, soon becomes hot; the knife-board is quickly warmed by the motion of the knife; water, when rapidly agitated by a paddle-wheel, has its temperature raised; and Sir H. Davy, describes an experiment, by which, from the friction of ice against ice, at a freezing temperature, each piece of ice was converted into water, the temperature of the water being several degrees higher than that of the ice.

(*d*) "Twisting or rending bodies asunder generates heat in a very sensible manner. Thus, if a bar of iron or wood be sharply twisted or broken, considerable heat is generated. Buffon observed that. if a beam of green timber were supported at one end, and weights were rapidly suspended on the other, so as to bend or break it, a violent hissing ensued, and smoke issued from both ends."—*Herapath.*

(*e*) *Chemical Mixtures.* The mixture of sulphuric acid and water, in equal parts, generates great heat.

On the contrary, when snow and salt are mixed together a great quantity of heat disappears.

ANSWERS TO EXERCISES ON PAGES 15—17.

1. (1) $-1\frac{1}{9}°$; $-\frac{8}{9}°$. (2) $7\frac{8}{9}°$; $5\frac{7}{9}°$. (3) $13\frac{1}{3}°$; $10\frac{2}{3}°$. (4) $-17\frac{7}{9}°$ $-14\frac{8}{9}°$. (5) $-21\frac{2}{3}°$; $17\frac{1}{3}°$. (6) $-42\frac{7}{9}°$; $-34\frac{8}{9}°$. 2. (1) $6\frac{1}{4}°$; $43\frac{1}{4}°$. (2) 25°; 77°. (3) 0°; 32°, (4) $-22\frac{1}{2}°$; $-8\frac{1}{2}°$. (5) −80°; −112°. (6) 150°; 302°. 3. (1) $60\frac{1}{5}°$; $12\frac{4}{5}°$. (2) 113°; 36°. (3) 230°; 88°. (4) 32°; 0°. (5) 5°; −12°. (6) $-11\frac{1}{5}°$; $-19\frac{1}{5}°$. 4. 50° Fah. 5. 10° Cent. and 50° Fah. 6. 10° Cent. and 50 Fah. 7. −40°. 8. Make each degree $\frac{4}{5}$ths that on Fahrenheit. 9. 20° Cent., 68° Fah. 10. 80° Fah. 11. 20° Cent., 68° Fah. 12. $-11\frac{3}{7}$ Cent., $11\frac{3}{7}$ Fah. 13. 24°. 14. 23°. 15. 59° Fah., 12° Reaum.; if d be the number of degrees, Fah. rises $\frac{9d}{5}$ and Reaum. $\frac{4d}{5}$. 16. $137\frac{1}{2}°$ 17. 122° Fah.